

TITLE OF THE INVENTION

MAGNETIC RANDOM ACCESS MEMORY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the
5 benefit of priority from the prior Japanese Patent
Application No. 2003-088413, filed March 27, 2003,
the entire contents of which are incorporated herein by
reference.

BACKGROUND OF THE INVENTION

10 1. Field of the Invention

The present invention relates to a magnetic random
access memory (MRAM), and more particularly to a
structure of a magnetic memory cell composed by using
elements capable of storing information of "1"/"0" by
15 the so-called tunneling magneto-resistive effect.

2. Description of the Related Art

Recently, various memories for storing information
by a new principle have been proposed. One of them
is MRAM in which magnetic memory cells composed of
20 magnetic tunnel junction (MTJ) elements for storing
information of "1"/"0" by making use of the tunneling
magneto-resistive effect (hereinafter referred to
as TMR effect) are arrayed in a matrix. Examples of
MRAM are disposed in US Patent No. 5,734,605 by Zhu et
25 al. and also in US Patent No. 5,768,183 by Zhu et al.

In the MRAM, plural bit lines for writing/reading
and plural write word lines are disposed in the

orthogonal direction, and MTJ elements are disposed
corresponding to each intersection. Each MTJ element
is provided with a spin direction such that the
long-side of rectangle is set along the write word line
5 and that the short-side is set along the bit line, and
along the long-side direction.

Each bit line is connected to each fixed layer of
plural MTJ elements of the same row or same column, and
each write word line is disposed so as to face closely
10 to each free layer of plural MTJ elements of the same
column or same row.

Writing to the MTJ element is achieved by passing
current in the write word lines and bit lines and
turning the spin direction of the MTJ element in
15 parallel or anti-parallel direction by using the
magnetic field generated by the current flowing in both
wirings.

The distance between the write word line and the
MTJ element must be longer than the distance between
20 the bit line and the MTJ element, and more current must
flow in the write word lines. The magnetic field
generated from the write word lines distributes along
a loop-shaped curve. Hitherto, since the magnetic
field intensity applied in the central portion and in
25 the end portion of the free layer of the MTJ element
is different, the writing current increases due to
an inverting magnetic field, which has been a problem

for practical use.

BRIEF SUMMARY OF THE INVENTION

According to an aspect of the present invention,
there is provided a magnetic random access memory
5 including: a first wiring and a second wiring disposed
so as to intersect each other; a magnetic tunnel
junction element having the tunneling magneto-resistive
effect and disposed at the intersection of the first
and second wirings, the magnetic tunnel junction
10 element having a structure in which a non-magnetic
layer is sandwiched between a fixed layer and a free
layer both made of a magnetic film, having a long-side
and a short-side of a rectangle, being provided with
a spin direction such that the long-side of rectangle
15 is set along the second wiring and that the short-side
thereof is set along the first wiring, and along the
long-side direction, and having an upper surface which
is upwardly convex in the central portion as viewed in
the short-side direction, with the long axis as a
20 center of convexity, and a lower surface which is
downwardly concave in the central portion as viewed in
the short-side direction, with the long axis as a
center of concavity; a conductive hard mask formed to
cover the upper surface of the magnetic tunnel junction
25 element; conductive contact plugs for electrically
connecting the hard mask and the first wiring; a
connection wiring to be electrically connected to the

lower surface of the magnetic tunnel junction element;
and an interlayer insulating film provided to be
interposed between the connection wiring and the second
wiring.

5 BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIG. 1 is a sectional view showing an outline of
a structure of an MTJ element for use in MRAM;

FIGS. 2A and 2B are views showing a spin direction
of two magnetic layers of the MTJ element in FIG. 1;

10 FIG. 3 is a diagram schematically showing
an example of layout of cell arrays of the MRAM;

FIG. 4 is a sectional view schematically showing
an example of a memory cell taken along line IV-IV in
FIG. 3;

15 FIG. 5 is a sectional view schematically showing
an example of a memory cell taken along line V-V in
FIG. 3;

FIG. 6 is a characteristic diagram showing a TMR
curve of the MTJ element;

20 FIG. 7 is a characteristic diagram showing
an asteroid curve of the MTJ element;

FIG. 8 is a sectional view of a memory cell in
MRAM according to a first embodiment of the invention;

FIG. 9 is a sectional view, different from FIG. 8,
25 of the memory cell in the MRAM according to the first
embodiment;

FIG. 10 is a sectional view showing a part of

a process of forming MRAM having the structure shown in
FIGS. 8 and 9;

FIG. 11 is a perspective view of an MTJ element in
the MRAM according to the first embodiment;

5 FIG. 12 is a sectional view of a memory cell in
MRAM according to a second embodiment of the invention;

FIG. 13 is a sectional view, different from
FIG. 12, of the memory cell in the MRAM according to
the second embodiment;

10 FIG. 14 is a sectional view showing a part of
a process of forming MRAM having the structure shown in
FIGS. 12 and 13;

FIG. 15 is a block circuit diagram of a DSL data
path portion of a digital subscriber line modem as one
15 of application examples of MRAM;

FIG. 16 is a block circuit diagram of a circuit
portion for realizing communication function in
a cellphone terminal as another application example
of MRAM;

20 FIG. 17 is a top view showing an example in which
the MRAM is applied to an MRAM card;

FIG. 18 is a top view of a transfer device of card
insert type for transferring data on the MRAM card in
FIG. 17;

25 FIG. 19 is a side view of the transfer device in
FIG. 18;

FIG. 20 is a side view of a transfer device of

fit-in type for transferring data on the MRAM card in
FIG. 17; and

FIG. 21 is a side view of a transfer device of
slide type for transferring data on the MRAM card in
5 FIG. 17.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, preferred
embodiments of the invention will be described in
detail below.

10 FIG. 1 is an outline view of a sectional structure
of an MTJ element for use in MRAM.

The MTJ element has a structure in which one
non-magnetic layer (tunnel barrier layer) 73 is
sandwiched between two magnetic layers 71, 72 made of
15 a ferromagnetic layer or ferromagnetic film. The MTJ
element having such structure stores information of
"1"/"0" depending on whether the spin direction of
the two magnetic layers 71, 72 is parallel or anti-
parallel.

20 Usually, an anti-ferromagnetic layer 74 is
disposed at one side of the two magnetic layers 71, 72.
In FIG. 1, the anti-ferromagnetic layer 74 is disposed
at the side of the magnetic layer 72. The anti-
ferromagnetic layer 74 is a member for easily rewriting
25 the information by fixing the spin direction of the one
magnetic layer 72, and varying the spin direction of
the other magnetic layer 71 only. Herein, the magnetic

layer 71 on the spin variable side is called a free layer or recording layer, and the magnetic layer 72 on the spin fixed side is called a fixed layer or spin layer.

5 FIGS. 2A and 2B show the spin direction of the two magnetic layers 71,72 of the MTJ element shown in FIG. 1.

 As shown in FIG. 2A, the two magnetic layers 71, 72 are same in the spin direction, that is, the arrow
10 direction in the drawing. In the case of the parallel direction, the tunnel resistance of the insulating layer 73 sandwiched between the two magnetic layers 71, 72 becomes the lowest, that is, the tunnel current is the largest.

15 As shown in FIG. 2B, when the spin directions of the two magnetic layers 71, 72 are anti-parallel, the tunnel resistance of the insulating layer 73 sandwiched between the two magnetic layers 71, 72 becomes the highest, that is, the tunnel current is the smallest.

20 In the MRAM, two states different in resistance value of the MTJ element correspond to the storage state of information "1" (state 1) and the storage state of information "0" (state 0).

 FIG. 3 schematically shows an example of plane
25 layout of part of cell arrays of MRAM.

 Plural bit lines BL for writing/reading, and plural write word lines WWL are disposed in orthogonal

directions, and MTJ elements are disposed corresponding to each intersection. Each MTJ element is provided with a spin direction such that the long-side of rectangle is set along the write word line WWL and that the short-side is set along the bit line BL, and along the long-side direction.

Each bit line BL is connected to each fixed layer of plural MTJ elements of the same row or same column, and each write word line WWL is disposed so as to face closely to each free layer of plural MTJ elements of the same column or same row.

FIG. 4 is a sectional view of a memory cell taken along line IV-IV in FIG. 3, and FIG. 5 is a sectional view of a memory cell taken along line V-V in FIG. 3.

In FIGS. 4 and 5, reference numeral 10 is a semiconductor substrate made of, for example, a P-type Si substrate, 11 is a shallow-trench-type isolation region (STI), 12 is a gate oxide film, 13 is an N⁺ impurity diffusion layer serving as a drain region or source region of NMOSFET TR for switching element, 14 is a gate electrode (GC) serving as a read word line RWL, 15, 16 and 17 are MTJ connection wirings composed of first metal wiring layer (M1), second metal wiring layer (M2), and third metal wiring layer (M3), respectively, 18 is a conductive contact plug for electrically connecting the first metal wiring layer 15 to the diffusion layer 13, 19 is a conductive contact

plug for electrically connecting from the second metal wiring layer 16 to the first metal wiring layer 15, 20 is a conductive contact plug for electrically connecting from the third metal wiring layer 17 to the second metal wiring layer 16, 21 is an MTJ element, 22 is a fourth wiring layer (M4), 23 is a conductive contact plug for electrically connecting the fourth metal wiring layer 22 to the MTJ element 21, and 24 is an interlayer insulation film.

10 As the wiring in FIG. 4, meanwhile, BL denotes the bit line for writing/reading, WWL denotes the write word line, SL denotes the source line and RWL denotes the read word line. The source line (SL) is connected to the grounding potential.

15 Referring now to FIGS. 3 to 6, the principle of writing operation on the MTJ element will be explained.

Writing to the MTJ element is achieved by passing current in the write word lines WWL and bit lines (data select lines) BL and turning the spin direction of the MTJ element in parallel or anti-parallel direction by using the magnetic field generated by the current flowing in both wirings.

That is, when writing information into the MTJ element, current is passed in the bit line BL in a first direction or reverse second direction depending on the write data to generate a magnetic field H_x , and current flowing only in the first direction is passed

in the write word line WWL to generate a magnetic field H_y , so that the information is written by using the combined magnetic field. At this time, when current flowing in the first direction is passed in the bit line BL, the spin direction of the MTJ element is parallel, or when current flowing in the second direction is passed in the bit line BL, the spin direction of the MTJ element is anti-parallel.

When reading out information from the MTJ element, the read word line RWL is activated, and only the switch element TR connected to the selected MTJ element is turned on to form a current route, and current is passed from the selected bit line BL to the grounding potential. As a result, since current depending on the resistance value flows only in the selected MTJ element, the information can be read out by detecting this current value.

Mechanism of varying the spin direction of the MTJ element will be briefly explained.

FIG. 6 shows the variation characteristic of the resistance value (TMR curve) by inversion of the magnetic field applied to the MTJ element. FIG. 7 shows an asteroid curve of the MTJ element.

As shown in the TMR curve in FIG. 6, when the magnetic field H_x is applied in the easy-axis direction of the MTJ element, the resistance value of the MTJ element is changed, for example, by about 17%. This

change rate, that is, the ratio of the resistance value before and after change is called an MR ratio. The MR ratio varies with the property of the magnetic layer of the MTJ element. At the present, MTJ elements with MR
5 ratio of about 50% are developed.

In the MTJ element, a combined magnetic field of the magnetic field H_x in the easy-axis direction and the magnetic field H_y in the hard-axis direction is applied. As indicated by the solid line and broken
10 line in FIG. 6, depending on the magnitude of the magnetic field H_y in the hard-axis direction, the magnitude of the magnetic field H_x in the easy-axis direction necessary for varying the resistance value of the MTJ element is changed.

By making use of this phenomenon, of the memory
15 cells in array layout, the data can be written only into the MTJ element disposed at the intersection of the selected write word line WWL and selected bit line BL. This operation is explained by referring to the
20 asteroid curve in FIG. 7.

As shown in FIG. 7, when the magnitude of the combined magnetic field of the magnetic field H_x in the easy-axis direction and the magnetic field H_y in the hard-axis direction is outside of the asteroid curve,
25 for example, at the black circle position, the spin direction of the magnetic layer of the MTJ element can be inverted.

To the contrary, when the magnitude of the combined magnetic field of the magnetic field Hx in the easy-axis direction and the magnetic field Hy in the hard-axis direction is inside of the asteroid curve, for example, at the white circle position, the spin direction of the magnetic layer of the MTJ element cannot be inverted.

Therefore, by varying the magnitude of the combined magnetic field of the magnetic field Hx in the easy-axis direction and the magnetic field Hy in the hard-axis direction and by changing the position of the magnitude of the combined magnetic field within the Hx-Hy plane, data writing to the MTJ element can be controlled.

First embodiment

MRAM according to a first embodiment has an array of MTJ elements as shown in FIG. 3. That is, plural bit lines BL for writing/reading (first wiring) and plural write word lines WWL (second wiring) are disposed in orthogonal directions, and MTJ elements are disposed corresponding to each intersection.

FIGS. 8 and 9 are sectional views showing examples of a structure of the MTJ element and MOSFET for switch, giving attention to one memory cell in the MRAM according to the first embodiment of the invention. The section in FIG. 8 corresponds to the section in FIG. 4, and the section in FIG. 9 corresponds to the

section in FIG. 5.

The structure shown in FIGS. 8 and 9 is only slightly different from the structure in FIGS. 4 and 5, and therefore parts corresponding to FIGS. 4 and 5 are identified with the same reference numerals and explanation is omitted, and only different points from FIGS. 4 and 5 are described below.

The MTJ element 21a used in the embodiment is similar to the MTJ element explained in FIG. 1 except that the central portion in the short-side direction around the long-side of rectangle or ellipse is swollen toward the direction of the bit line, that is, curved in a convex form upwardly. That is, the tunneling magneto-resistive effect is provided by a structure in which a tunnel barrier film 73 is sandwiched between a free layer 71 on the spin variable side and a fixed layer 72 on the spin fixed side. Thus, the easy-to-write axis or spin direction is provided such that the long-side is set along the write word line WWL, and that the short-side is set along the bit line BL.

A conductive hard mask 25 made of, for example, Ta is formed so as to cover the curved outer surface of this MTJ element 21a. The MTJ element 21a and bit line BL are electrically connected by the conductive contact plug 23 by way of the hard mask 25. An MTJ connection wiring 17a made of metal, such as Ta, is formed so as to contact with the curved inner surface of the MTJ

element 21a. The interlayer insulating film 24 is interposed between the connection wiring 17a and the write word line WWL. The interlayer insulating film 24 projects toward the direction of the bit line BL in the portion facing the curved inner surface of the MTJ element 21a more than the other portion consecutive thereto.

In the MRAM of the first embodiment, the long-side direction of the MTJ element 21a, that is, the spin direction is orthogonal to the bit line BL, and the MTJ element 21a is warped so as to coincide substantially with the magnetic field curve generated from the write word line WWL. Therefore, the magnetic field intensities applied in the central portion and end portion in the width direction of the free layer 71 of the MTJ element 21a in the curved state, that is, the short-side direction, are equal to each other. As a result, the inverting magnetic field is decreased, the writing efficiency is enhanced, and the writing current is decreased. In this case, in order to enhance the magnetic field intensity applied to the end portion in the width direction of the free layer of the MTJ element 21a, preferably the length of the chord between the both leading ends of the short-side of the MTJ element 21a in the curved state should be wider than the width of the write word line WWL.

FIG. 10 shows a structure in a section vertical

to the write word line in an example of a process of forming the MRAM having the structure shown in FIGS. 8 and 9.

5 The interlayer insulating film 24 is composed of plural layers of insulating film, but only a part of an insulating film 241 is shown herein for the sake of simplicity of explanation.

10 First, the isolation region (STI) 11 is formed at a selected position of the surface layer of the P-type Si substrate 10. Next, the gate insulating film 12 of NMOSFET for switch, the gate electrode (GC) (read word line RWL) 14, and the drain region and source region 13 made of a N^+ diffusion layer are formed. The contact plugs 18 are formed on the drain region and source
15 region 13, and the first metal wiring layers (M1) 15 are formed on the contact plugs 18. The contact plug 19 is formed on the first metal wiring layer 15, and the second metal wiring layer (M2) 16 of, for example, Cu wiring is formed on the contact plug 19. Further,
20 the interlayer insulating film 241 of about 600 nm in thickness, and a silicon nitride (SiN) film 31 of about 300 nm in thickness are deposited.

By lithographic technique and reactive ion etching (RIE) technique, the SiN film 31 is left over in a
25 desired pattern, and using the SiN film 31 as a mask, the interlayer insulating film 241 is processed by etching (milling) at an oblique angle.

At this time, in order to form the MTJ element 21a as repetitive pattern in a later process, the mutual space regions of the MTJ elements 21a are formed in grooves to form repetitive pattern. As a result, of the interlayer insulating film 241, the portion on which the MTJ element 21a is formed in a post-process is formed in an upward convex form as compared with other portions. That is, the thickness of the interlayer insulating film 241 of the MTJ element 21a forming portion is thicker than other portion.

After removing the pattern of the SiN film 31, as shown in FIG. 8, the contact plug 20 is formed on the second metal wiring layer 16, and further the third metal wiring layer (M3) 17a of, for example, Ta is deposited in a thickness of about 30 nm, and each layer forming the MTJ element 21a is deposited sequentially, and the hard mask 25 of, for example, Ta is formed in a thickness of about 150 nm. Herein, as the free layer of the MTJ element 21a, usually, NiFe is used, but other materials may be used, such as CoNiFe, CoFe, CoCr, or CoPt.

By lithographic technique and RIE technique, the hard mask 25 and MTJ element 21a are processed in a desired pattern, and further by lithographic technique and RIE technique, the third metal wiring layer 17a is processed in a desired pattern to form an MTJ connection wiring. In this case, parts of the

third metal wiring layer 17a, that is, the convex portion at the upper side of the interlayer insulating film 241 mentioned above and the MTJ element 21a formed thereon are curved in a convex shape to the upper side.

5 Next, the contact plug 23 and fourth metal wiring layer (M4) 22 are formed to contact with the hard mask 25 at the upper side of the MTJ element 21a.

 The curved surface may be formed also by making use of difference in the coefficient of thermal expansion due to difference in thickness ratio or
10 material of the MTJ element 21a and hard mask 25.

 FIG. 11 is a detailed description of an example of a laminated structure of the MTJ element 21a shown in FIG. 8.

15 The MTJ element 21a is formed by laminating a buffer layer 70, the anti-ferromagnetic layer 74, the fixed layer 72, the tunnel barrier layer 73, the free layer 71, and a cap layer 75 sequentially on the third metal wiring layer (M3) 17a made of Ta about 30 nm in
20 thickness as shown, for example, in FIG. 8, and further forming the hard mask 25 of, for example Ta about 150 nm in thickness in FIG. 8 thereon.

 Herein, the buffer layer 70 is made of, for example, R_n , and is about 3 nm in thickness. The
25 anti-ferromagnetic layer 74 is made of, for example, IrMn, and is about 10 nm in thickness. The fixed layer 72 is made of, for example, CoFe, and is about 3 nm in

thickness. The tunnel barrier layer 73 is made of,
for example, Al_2O_3 , and is about 1.5 nm in thickness.
The free layer 71 is made of, for example, NiFe, and is
about 6 nm in thickness. The cap layer 75 is made of,
5 for example, Ru, and is about 10 nm in thickness.

As an example of size of the MTJ element 21a, the
width W in the short-side direction is 0.4 μm , the
length L in the long-side direction is 1.2 μm , the
upper side is curved in a convex form such that the
10 both ends B may be lower by about 5 nm than the apex A
in the middle of the short-side direction, and the
radius of curvature at this time is about 4 μm .

Second embodiment

MRAM according to a second embodiment has an array
15 of MTJ elements as shown previously in FIG. 3, and
plural bit lines BL for writing/reading (first wiring)
and plural write word lines WWL (second wiring) are
disposed in orthogonal directions, and MTJ elements 21b
are disposed corresponding to each intersection.

20 FIGS. 12 and 13 are sectional views showing
examples of a structure of the MTJ element and MOSFET
for switch, giving attention to one memory cell in
the MRAM according to the second embodiment of the
invention. The section in FIG. 12 corresponds to
25 the section in FIG. 4, and the section in FIG. 13
corresponds to the section in FIG. 5.

The structure shown in FIGS. 12 and 13 is similar

to the structure in FIGS. 8 and 9, except that only the curved state of the MTJ element 21b is different.

That is, in the MTJ element 21b used in the second embodiment, the central portion of the long-side direction around the short-side of rectangle or ellipse is swollen toward the direction of the write word line WWL, that is, curved downward in a convex form. That effect is provided by a structure in which the tunnel barrier film 73 is sandwiched between the free layer 71 on the spin variable side and the fixed layer 72 on the spin fixed side. Thus, the easy-to-write axis is provided such that the long-side is set along the write word line WWL, and that the short-side is set along the bit line BL.

A conductive hard mask 26 made of, for example, Ta is formed so as to cover the curved inner surface of this MTJ element 21b. The MTJ element 21b and bit line BL are electrically connected by the conductive contact plug 23 by way of the hard mask 26. An MTJ connection wiring 17b made of metal, such as Ta, is formed so as to contact with the curved outer surface of the MTJ element 21b. A part of the interlayer insulating film 24 is interposed between the connection wiring 17b and the write word line WWL. This part of the interlayer insulating film 24 is dented toward the direction of the write word line WWL in the portion facing inside

and outside of the curved surface of the MTJ element 21b more than the other portion consecutive thereto. In other words, the film thickness of the interlayer insulating film 24 in the portion on which the MTJ element 21b is formed is thinner than the other portion.

In the MRAM of the second embodiment, the long-side direction of the MTJ element 21b, that is, the spin direction is orthogonal to the bit line BL, and the MTJ element 21b is warped so as to coincide nearly with the magnetic field curve generated from the bit line BL. Therefore, the magnetic field intensities applied in the central portion and end portion in the longitudinal direction of the free layer of the MTJ element 21b in the curved state, that is, the long-side direction, are equal to each other. As a result, the inverting magnetic field is decreased, the writing efficiency is enhanced, and the writing current is decreased. In this case, in order to enhance the magnetic field intensity applied to the end portion in the longitudinal direction of the free layer of the MTJ element 21b, preferably the length of the chord between the both leading ends of the long-side of the MTJ element 21b in the curved state should be wider than the width of the bit line BL.

FIG. 14 is a sectional view showing a structure in a section vertical to the bit line in an example of a

process of forming the MTJ element having the structure shown in FIGS. 12 and 13. The interlayer insulating film 24 is composed of plural layers of insulating film, but only a part of an insulating film 241 is
5 shown herein for the sake of simplicity of explanation.

First, the isolation region (STI) 11 is formed at a selected position of the surface layer of the P-type Si substrate 10. Next, the gate insulating film 12 of NMOSFET for switch, the gate electrode (GC) (read word
10 line RWL) 14, and the drain region and source region 13 made of a N^+ diffusion layer are formed. The contact plugs 18 are formed on the drain region and source region 13, and the first metal wiring layers (M1) 15 are formed on the contact plugs 18. The contact plug
15 19 is formed on the first metal wiring layer 15, and the second metal wiring layer (M2) 16 of, for example, Cu wiring is formed, and also the interlayer insulating film 241 of about 600 nm in thickness, and a silicon nitride (SiN) film 31 of about 300 nm in thickness are
20 deposited.

By lithographic technique and RIE technique, the SiN film 31 is formed in a desired pattern, and using the SiN film 31 as a mask, the interlayer insulating film 241 is processed by etching (milling) at an
25 oblique angle. At this time, in order to form the MTJ element 21b as repetitive pattern in a post-process, the repetitive pattern is formed such that the region

intended to dispose the MTJ elements 21b is formed in grooves.

After removing the SiN film 31, as shown in FIG. 12, the contact plug 20 is formed on the second metal wiring layer 16, and further the third metal wiring layer (M3) 17a of, for example, Ta is deposited in a thickness of about 30 nm, and each layer forming the MTJ element 21b is deposited sequentially, and the hard mask 26 of, for example, Ta is formed in a thickness of about 150 nm. Herein, as the free layer of the MTJ element 21b, usually, NiFe is used, but other materials may be used, such as CoNiFe, CoFe, CoCr, or CoPt.

By lithographic technique and RIE technique, the hard mask 26 and MTJ element 21b are processed in a desired pattern, and further by lithographic technique and RIE technique, so that the third metal wiring layer 17b is processed in a desired pattern to form an MTJ connection wiring.

Next, the contact plug 23 and fourth metal wiring layer (M4) 22 are formed to contact with the hard mask 26 at the upper side of the MTJ element 21b.

The curved surface may be formed also by making use of difference in the coefficient of thermal expansion due to difference in thickness ratio or material of the MTJ element 21b and hard mask 26.

In the foregoing embodiments, in order to realize

large capacity and high density integration, one cell array unit may be composed of memory cell array of plural MTJ elements disposed in matrix, a plurality of write word lines WWL, and a plurality of bit lines BL, and plural cell array units may be stacked up on a semiconductor substrate to compose a cell array laminated structure.

The invention may be easily applied in a multi-layer structure of recording layers of MTJ elements in each embodiment.

The MRAM according to the first and second embodiments may be applied in various examples. Some of the applicable examples are explained below. Applicable example 1

As one of applicable examples of the MRAM, FIG. 15 shows a digital subscriber line (DSL) data path portion of a digital subscriber line (DSL) modem. This modem includes a programmable digital signal processor (DSP) 100, an analog-to-digital converter (A/D) and digital-to-analog converter (D/A) 111, a transmission driver 112, and a receiver amplifier 113. In FIG. 15, the band pass filter is omitted, and an MRAM 114 and an EEPROM 115 are shown instead as an optional memory of various types capable of holding a line code program.

In this example, as the memory for holding the line code program, two memories MRAM and EEPROM are used, but the EEPROM may be replaced by the MRAM, that

is, without using two memories, only the MRAM may be used.

Applicable example 2

As another applicable example of the MRAM,
5 FIG. 16 shows a portion for realizing communication function in a cellphone terminal 300. As shown in FIG. 16, the portion for realizing the communication function comprises a transmission and reception antenna 201, an antenna duplexer 202, a receiver 203, a base
10 band processor 204, a digital signal processor (DSP) 205 used as audio codec, a loudspeaker 206, a microphone 207, a transmitter 208, and a frequency synthesizer 209.

Also as shown in FIG. 16, the cellphone terminal
15 300 has a controller 200 for controlling the parts of the cellphone terminal. The controller 200 is a microcomputer composed by connecting a CPU 221, a ROM 222, an MRAM 223, and a flash memory 224 by way of a CPU bus 225.

20 Herein, the ROM 222 preliminarily stores programs to be executed in the CPU 221, and necessary data such as display font. The MRAM 223 is mainly used as a working region, and specifically it is used when storing necessary data in the midst of calculation as
25 required during program execution by the CPU 221, or when temporarily storing data to be used in communications between the controller 200 and other parts. The

flash memory 224 stores the immediate preceding setting conditions or the like even if the power source of the cellphone terminal 300 is turned off, or stores the setting parameters when using by setting in the same conditions when the power source is turned on again. That is, the flash memory 224 is a nonvolatile memory holding the stored data even if the power source of the cellphone terminal is turned off.

In this example, the ROM 222, MRAM 223, and flash memory 224 are used, but the flash memory 224 may be replaced by the MRAM, or the ROM 222 may be also replaced by the MRAM.

In FIG. 16, reference numeral 211 is an audio data reproduction processor, 212 is an external terminal connected to the audio data reproduction processor 211, 213 is an LCD controller, 214 is an LCD connected to the LCD controller 213, 215 is a ringer, 231 is an interface (I/F) provided between a CPU bus 225 and an external memory slot 232, 233 is an interface (I/F) provided between the CPU bus 225 and a key operation unit 234, 235 is an interface (I/F) provided between the CPU bus 225 and an external terminal 236, and an external memory 240 is inserted into the external memory slot 232.

Applicable example 3

FIGS. 17 to 21 show an example in which the MRAM is applied in a card holding media contents such as

smart media (MRAM card).

5 In a top view in FIG. 17, reference numeral 400 is an MRAM card main body, 401 is an MRAM chip, 402 is an opening, 403 is a shutter, and 404 denotes plural external terminals. The MRAM chip 401 is contained in the MRAM card main body 400, and is exposed to outside through the opening 402. While carrying the MRAM card, the MRAM chip 401 is covered with the shutter 403. The shutter 403 is made of a material having an effect of shielding an external magnetic field, such as ceramic material. When transferring the data, the shutter 403 is released, and the MRAM chip 401 is exposed. The external terminals 404 are for taking out the contents data stored in the MRAM card to outside.

15 FIGS. 18 and 19 are a top view and a side view of a transfer device of card insert type for transferring data on the MRAM card. A second MRAM card 450 used by an end user is inserted from a slit 510 in a transfer device 500, and pushed in until stopped by a stopper 520. The stopper 520 is also used as a member for positioning the first MRAM card 550 and second MRAM card 450. With the second MRAM card 450 disposed at specified position, the data stored in the first MRAM card 550 is transferred into the second MRAM card 450.

25 FIG. 20 is a side view of a transfer device of fit-in type. As indicated by arrow in the drawing, in this type, aiming at the stopper 520, the second

MRAM card 450 is fitted on the first MRAM card 550.
The transfer method is same as that in the cart insert
type, and explanation is omitted.

FIG. 21 is a side view of a transfer device of
5 slide type. In the same manner as in the CD-ROM drive
or DVD drive, a receiving tray slide 560 is provided in
the transfer device 500, and this receiving tray slide
560 slides in the horizontal direction as indicated by
arrow in the drawing. When the receiving tray slide
10 560 moves to the state indicated by the broken line in
the drawing, the second MRAM card 450 is put on the
receiving tray slide 560. Then, the receiving tray
slide 560 conveys the second MRAM card 450 into the
inside of the transfer device 500. The second MRAM
15 card 450 is conveyed until its leading end hits against
the stopper 520, and the data is transferred, same as
in the card insert type, and explanation is omitted.

Additional advantages and modifications will
readily occur to those skilled in the art. Therefore,
20 the invention in its broader aspects is not limited to
the specific details and representative embodiments
shown and described herein. Accordingly, various
modifications may be made without departing from the
spirit or scope of the general inventive concept as
25 defined by the appended claims and their equivalents.